

SECTION 7

GROUND WATER SAMPLING

PERFORMANCE OBJECTIVES:

- To collect a sample representative of ground water residing in the formation of interest.
- To reduce the potential bias caused by the sampling equipment used to obtain the sample.

7.1 Introduction

Ground water sampling may be required for a variety of reasons, such as examining potable or industrial water supplies, checking for and/or tracking contaminant plume movement in the vicinity of a land disposal or spill site, Resource Conservation Recovery Act (RCRA) compliance monitoring, or examining a site where historical information is minimal or non-existent but where it is thought that ground water contamination may have occurred.

Ground water samples are usually obtained from either temporarily or permanently installed ground water monitoring wells. They can also be obtained, however, anywhere ground water is present, such as in a pit or a dug or drilled hole.

Occasionally, the ground water source may not be in the ideal location to meet a particular objective (e.g., to track a contaminant plume). In that case, either a temporary or permanent monitoring well should be installed. An experienced and knowledgeable person will need to locate the well and supervise its installation so that samples will be representative of the ground water.

Additional guidance is given in RCRA Ground-Water Monitoring: Technical Guidance (1) and Chapter 11 of SW-846 (2). The ground water sampling procedures described in this SOP will meet or exceed the requirements of these documents.

Ground water sampling procedures can be sub-divided into two areas, purging and sampling, each of which has different goals and objectives. Within the topic of purging, it is necessary, because of the inherently different characteristics of the two types of wells, to address permanent and temporary wells separately. The procedures and techniques which follow in this section reflect these differences.

7.2 Purging

7.2.1 Purging and Purge Adequacy

Purging is the process of removing stagnant water from a monitoring well, immediately prior to sampling, causing its replacement by ground water from the adjacent formation, which is representative of actual aquifer conditions. In order to determine when a well has been adequately purged, field investigators should: 1) monitor the pH, specific conductance, temperature, and turbidity of the ground water removed during purging; and 2) observe and record the volume of water removed.

Prior to initiating the purge, the amount of water standing in the water column (water inside the well riser and screen) should be determined. To do this, the diameter of the well should be determined and the water level and total depth of the well are measured and recorded. Specific methodology for obtaining these measurements is found in Section 15.8 of this SOP. Once this information is obtained, the volume of water to be purged can be determined using one of several methods. One is the equation:

$$V = 0.041 d^2 h$$

Where: h = depth of water in feet
d = diameter of well in inches
V = volume of water in gallons

Alternatively, the volume may be determined using a casing volume per foot factor for the appropriate diameter well, similar to that in Table 7.2.1. The water level is subtracted from the total depth, providing the length of the water column. This length is multiplied by the factor in the Table 7.2.1 which corresponds to the appropriate well diameter, providing the amount of water, in gallons, contained in the well. Other acceptable methods include the use of nomographs or other equations or formulae.

With respect to volume, an adequate purge is normally achieved when three to five times the volume of standing water in the well has been removed. The field notes should reflect the single well volume calculations or determinations, according to one of the above methods, and a reference to the appropriate multiplication of that volume, i.e., a minimum three well volumes, clearly identified as a purge volume goal.

With respect to the ground water chemistry, an adequate purge is achieved when the pH, specific conductance, and temperature of the ground water have stabilized and the turbidity has either stabilized or is below 10 Nephelometric Turbidity Units (NTUs). Ten NTUs is the goal for most ground water sampling objectives. This is twice the Primary Drinking Water standard of 5 NTUs. Stabilization occurs when pH measurements remain constant within 0.1 Standard Unit (SU), specific conductance varies no more than 10 percent, and the temperature is constant for at least three consecutive readings. There are no criteria establishing how many sets of measurements are adequate for the determination of stability. If the calculated purge volume is small, the measurements should be taken frequently to provide a sufficient number of measurements to evaluate stability. If the purge volume is large, measurements taken every 15 minutes may be sufficient.

If, after three well volumes have been removed, the chemical parameters have not stabilized according to the above criteria, additional well volumes may be removed. If the parameters have not stabilized within five volumes, it is at the discretion of the project leader whether or not to collect a sample or to continue purging. The conditions of sampling should be noted in the field log.

TABLE 7.2.1
WELL CASING DIAMETER vs. VOLUME

| WELL CASING DIAMETER vs. VOLUME (GALS.)/FEET of WATER | |
|---|------------------------|
| CASING SIZE | GALLONS/FT of WATER |
| 1 | 0.041 |
| 2 | 0.163 |
| 3 | 0.367 |
| 4 | 0.653 |
| 5 | 1.02 |
| 6 | 1.469 |
| 7 | 1.999 |
| 8 | 2.611 |
| 9 | 3.305 |
| 10 | 4.08 |
| 11 | 4.934 |
| 12 | 5.875 |

In some situations, even with slow purge rates, a well may be pumped or bailed dry (evacuated). In these situations, this generally constitutes an adequate purge and the well can be sampled following sufficient recovery (enough volume to allow filling of all sample containers). It is not necessary that the well be evacuated three times before it is sampled. The pH, specific conductance, temperature, and turbidity should be measured, during collection of the sample from the recovered volume, as the measurements of record for the sampling event.

Attempts should be made to avoid purging wells to dryness. This can be accomplished, for example, by slowing the purge rate. If a well is pumped dry, it may result in the sample being comprised partially of water contained in the sand pack, which may be reflective, at least in part, of initial, stagnant conditions. In addition, as water re-enters a well that is in an evacuated condition, it may cascade down the sand pack or the well screen, stripping volatile organic constituents that may be present and/or introducing soil fines into the water column.

Equipment Available

Monitoring well purging is accomplished by using in-place plumbing and dedicated pumps or, by using portable pumps/equipment when dedicated systems are not present. The equipment may consist of a variety of pumps, including peristaltic, large and small diameter turbine (electric submersible), bladder, centrifugal, gear-driven positive displacement, or other appropriate pumps. The use of any of these pumps is usually a function of the depth of the well being sampled and the amount of water that is to be removed during purging. Whenever the head difference between the sampling location and the water level is less than the limit of suction and the volume to be removed is reasonably small, a peristaltic pump should be used for purging. Appendix E of this SOP contains the operating instructions for all pumps commonly used during Branch ground water investigations.

Bailers may also be used for purging in appropriate situations, however, their use is discouraged. Bailers tend to disturb any sediment that may be present in the well, creating or increasing sample turbidity. If a bailer is used, it should be a closed-top Teflon® bailer.

7.2.2 Purging Techniques (Wells Without Plumbing or In-Place Pumps)

For permanently installed wells, the depth of water and depth of the well should be determined (if possible) before purging. Electrical water level indicators/well sounders can be used for this purpose. It is standard practice to mark the top of casing, providing a point of reference from which these measurements will be consistently made. Field investigators should look for these markings when taking these measurements. Extreme caution should be exercised during this procedure to prevent cross-contamination of the wells. This is a critical concern when samples for trace organic compounds or metals analyses are collected. At a minimum, the well sounding device should be cleaned by washing in a laboratory detergent solution, followed by rinses with tap water and analyte-free water. After cleaning, it should be placed in a clean plastic bag or wrapped in foil.

Purging with Pumps

When peristaltic pumps or centrifugal pumps are used, only the intake line is placed into the water column. The line placed into the water should be either standard-cleaned (see Appendix B) Teflon® tubing, for peristaltic pumps, or standard-cleaned stainless steel pipe attached to a hose for centrifugal pumps.

When submersible pumps (bladder, turbine, displacement, etc.) are used, the pump itself is lowered into the water column. The pump must be cleaned as specified in Appendix B.

Purging with Bailers

Standard-cleaned (Appendix B) closed-top Teflon® bailers with Teflon® leaders and new nylon rope are lowered into top of the water column, allowed to fill, and removed. The water is either discarded or contained and managed as investigation derived waste. It is critical that bailers be slowly and gently immersed into the top of the water column, particularly during final stages of purging, to minimize turbidity and disturbance of volatile organic constituents. The use of bailers for purging and sampling is discouraged because the correct technique is highly operator dependent.

Field Care of Purging Equipment

Regardless of which method is used for purging, new plastic sheeting should be placed on the ground surface around the well casing to prevent contamination of the pumps, hoses, ropes, etc., in the event they need to be placed on the ground during the purging or they accidentally come into contact with the ground surface. It is preferable that hoses used in purging that come into contact with the ground water be kept on a spool or contained in a plastic-lined tub, both during transporting and during field use, to further minimize contamination from the transporting vehicle or ground surface.

Purging Entire Water Column

The pump/hose assembly or bailer used in purging should be lowered into the top of the standing water column and not deep into the column. This is done so that the purging will "pull" water from the formation into the screened area of the well and up through the casing so that the entire static volume can be removed. If the pump is placed deep into the water column, the water above the pump may not be removed, and the subsequent samples, particularly if collected with a bailer, may not be representative of the ground water.

It is recommended that no more than three to five feet of hose be lowered into the water column. If the recovery rate of the well is faster than the pump rate and no observable draw down occurs, the pump should be raised until the intake is within one foot of the top of the water column for the duration of purging. If the pump rate exceeds the recovery rate of the well, the pump will have to be lowered, as needed, to accommodate the draw down. After the pump is removed from the well, all wetted portions of the hose and the pump should be cleaned as outlined in Appendix B of this SOP.

Careful consideration shall be given to using pumps to purge wells which are excessively contaminated with oily compounds, because it may be difficult to adequately decontaminate severely contaminated pumps under field conditions. When wells of this type are encountered, alternative purging methods, such as bailers, should be considered.

General Low Flow/Low Stress Method Preference

The device with the lowest pump or water removal rate and the least tendency to stress the well during purging should be selected for use. For example, if a bailer and a peristaltic pump both work in a given situation, the pump should be selected because it will greatly minimize turbidity, providing a higher quality sample (Section 7.2.4 contains a description of low flow purging and sampling with a peristaltic pump used in a temporary well). If a Fultz® pump or a Grundfos Redi-Flo2® could both be used, the Redi-Flo2® may be given preference because the speed can be controlled to provide a lower pump rate, thereby minimizing turbidity.

Low Flow/Low Volume Purging Techniques/Procedures

Alternatives to the low flow purging procedures exist and may be acceptable. The low flow/low volume purging is a procedure used to minimize purge water volumes. The pump intake is placed within the screened interval at the zone of sampling, preferably, the zone with the highest flow rate. Low flow rate purging is conducted after hydraulic conditions within the well have re-stabilized, usually within 24 to 48 hours. Flow rates should not exceed the recharge rate of the aquifer. This is monitored by measuring the top of the water column with a water level recorder or similar device while pumping. These techniques, however, are only acceptable under certain hydraulic conditions and are not considered standard procedures.

7.2.3 Purging Techniques - Wells with In-Place Plumbing

Wells with in-place plumbing are commonly found at municipal water treatment plants, industrial water supplies, private residences, etc. Many permanent monitoring wells at active facilities are also equipped with dedicated, in-place pumps. The objective of purging wells with in-place pumps is the same as with monitoring wells without in-place pumps, i.e., to ultimately collect a sample representative of the ground water. Among the types of wells identified in this section, two different approaches are necessary. The permanent monitoring wells with in-place pumps should, in all respects, be treated like the monitoring well without pumps. They generally are sampled only occasionally and require purging as described for wells without in-place pumps, i.e., 3 to 5 well volumes and stable parameters.

In the case of the other types of wells, however, not enough is generally known about the construction aspects of the wells to apply the same criteria as used for monitoring wells, i.e., 3 to 5 well volumes. The volume to be purged in these situations, therefore, depends on several factors: whether the pumps are running continuously or intermittently and whether or not any storage/pressure tanks are located between the sampling point and the pump. The following considerations and procedures should be followed when purging wells with in-place plumbing under the conditions described.

Continuously Running Pumps

If the pump runs more or less continuously, no purge (other than opening a valve and allowing it to flush for a few minutes) is necessary. If a storage tank is present, a spigot, valve or other sampling point should be located between the pump and the storage tank. If not, locate the valve closest to the tank. Measurements of pH, specific conductance, temperature, and turbidity are recorded at the time of sampling.

Intermittently Running Pumps

If the pump runs intermittently, it is necessary to determine, if possible, the volume to be purged, including storage/pressure tanks that are located prior to the sampling location. The pump should then be run continuously until the required volume has been purged. If construction characteristics are not known, best judgement should be used in establishing how long to run the pump prior to collecting the sample. Generally, under these conditions, 30 minutes will be adequate. Measurements of pH, specific conductance, temperature and turbidity should be made and recorded at intervals during the purge and the final measurements made at the time of sampling.

7.2.4 Purging Techniques - Temporary Monitoring Wells

Temporary ground water monitoring wells differ from permanent wells because temporary wells are installed in the ground water for immediate sample acquisition. Wells of this type may include standard well screen and riser placed in boreholes created by hand augering, power augering, or by drilling. They may also consist of a rigid rod and screen that is pushed, driven, or hammered into place to the desired sampling interval, such as the Direct Push Wellpoint®, the Geoprobe® and the Hydropunch®. As such, the efforts to remove several volumes of water to replace stagnant water do not necessarily apply in these situations, because generally, stagnant water is non-existent. It is important to note, however, that the longer a temporary well is in place and not sampled, the more appropriate it may be to apply, to the extent possible, standard permanent monitoring well purging criteria to it.

In cases where the temporary well is to be sampled immediately after installation, purging is conducted primarily to mitigate the impacts of installation. In most cases, temporary well installation procedures disturb

the existing aquifer conditions, resulting primarily in increased turbidity. Therefore, the goal of purging is to reduce the turbidity and remove the volume of water in the area directly impacted by the installation procedure. Low turbidity samples in these types of wells are typically and routinely achieved by the use of low-flow purging and sampling techniques.

The following low-flow purging technique using peristaltic pumps has been used routinely to achieve acceptably low NTU values in a variety of temporary monitoring well applications.

In purging situations where the elevation of the top of the water column is no greater than approximately 25 feet below the pump head elevation, a peristaltic pump may be used to purge temporary wells. Enough tubing is deployed to reach the bottom of the temporary well screen. At the onset of purging, the tubing is slowly lowered to the bottom of the screen and is used to remove any formation material which may have entered the well screen during installation. This is critical to ensuring rapid achievement of low turbidity conditions. After the formation material is removed from the bottom of the screen, the tubing is slowly raised through the water column to near the top of the column. The tubing can be held at this level to determine if the pump is lowering the water level in the well. If not, secure the tubing at the surface to maintain this pumping level.

If the water column is lowered, and the pump is not variable speed, continue to lower the tubing as the water column is lowered. If a variable speed peristaltic pump is being used and draw down is observed on initiation of pumping, reduce the pump speed and attempt to match the draw down of the well. Sustained pumping at these slow rates will usually result in a relatively clear, low turbidity sample. If the draw down stabilizes, maintain that level, however, if it continues to lower, "chase" the water column until the well is evacuated. In this case, the recovered water column may be relatively free of turbidity and can be sampled. It may take several episodes of recovery to provide enough volume for a complete sample.

With many of the direct push sampling techniques, no purging is conducted. The sampling device is simply pushed to the desired depth and opened and the sample is collected and retrieved.

7.3 Sampling

Sampling is the process of obtaining, containerizing, and preserving the ground water sample after the purging process is complete. Non-dedicated pumps for sample collection generally should not be used. Many pumps are made of materials, such as brass, plastic, rubber, or other elastomer products which may cause chemical interferences with the sample. Their principle of operation may also render them unacceptable as a sample collection device. The pump may be turbine driven, which may release volatile organic constituents. It is recognized that there are situations, such as industrial or municipal supply wells or private residential wells, where a well may be equipped with a dedicated pump from which a sample would not normally be collected. Discretion should always be used in obtaining a sample.

****Wells should be sampled immediately upon completion of purging operations. If the well is evacuated during the purging procedures, the sample should be collected as soon as a sufficient volume of water has recovered in the well.****

7.3.1 Equipment Available

Because of the problems with most pumps described in the preceding paragraph, only three devices should be used to collect ground water samples from most wells. These are the peristaltic pump/vacuum jug assembly, a stainless steel and Teflon® bladder pump, and a closed-top, Teflon® bailer.

Other monitoring equipment used during sampling includes water level indicators, pH meters, thermometers, conductivity bridges, and nephelometers.

7.3.2 Sampling Techniques - Wells With In-Place Plumbing

Samples should be collected following purging from a valve or cold water tap as near to the well as possible, preferably prior to any storage/pressure tanks that might be present. Remove any hose that may be present before sample collection and reduce the flow to a low level to minimize sample disturbance, particularly with respect to volatile organic constituents. Samples should be collected directly into the appropriate containers (see Standard Sample Containers, Appendix A). Also, refer to the Potable Water Supply discussion in Section 2.8. All measurements for pH, specific conductance, temperature, and turbidity should be recorded at the time of measurement.

7.3.3 Sampling Techniques - Wells without Plumbing

Following purging, samples should be collected using a peristaltic pump/vacuum jug assembly, a Teflon®/stainless steel bladder pump, or a closed-top Teflon® bailer. These techniques are described below.

Peristaltic pump/vacuum jug

The peristaltic pump/vacuum jug can be used for sample collection because it allows for sample collection without the sample coming in contact with the pump tubing. This is accomplished by placing a Teflon® transfer cap assembly onto the neck of a standard cleaned 4-liter (1-gallon) glass container. Teflon® tubing (¼-inch O.D.) connects the container to both the pump and the sample source. The pump creates a vacuum in the container, thereby drawing the sample into the container without it coming into contact with the pump tubing.

Samples for volatile organic compound analysis should be collected using a bailer or by filling the Teflon® tube, by one of two methods, and allowing it to drain into the sample vials. The tubing can be momentarily attached to the pump to fill the tube with water. After the initial water is discharged through the pump head, the tubing is quickly removed from the pump and a gloved thumb placed on the tubing to stop the water from draining out. The tubing is then removed from the well and the water allowed to drain into the sample vials. Alternatively, the tubing can be lowered into the well the desired depth and a gloved thumb placed over the end of the tubing. This method will capture the water contained in the tubing. It can then be removed from the well and the water collected by draining the contents of the tubing into the sample vials. Under no circumstances should the sample for volatile organic compound analysis be collected from the content of any other previously filled container. All equipment should be cleaned using the procedures described in Appendix B. Also, refer to the Potable Water Supply discussion, Section 2.2, for additional information.

Bladder Pumps

After purging has been accomplished with a bladder pump, the sample is obtained directly from the pump discharge. If the discharge rate of the pump, during purging, is too great, so as to make sample collection difficult, care should be taken to reduce the discharge rate at the onset of actual sample collection. This is necessary to minimize sample disturbance, particularly with respect to samples collected for volatile organic compounds analysis.

Bailers

When bailing, new plastic sheeting should be placed on the ground around each well to provide a clean working area. The nylon rope should be attached to the bailer via a Teflon® coated stainless steel wire. This coated wire is semi-permanently attached to the bailer and is decontaminated for reuse as the bailer is cleaned. The bailer should be gently immersed in the top of the water column until just filled. At this point, the bailer should be carefully removed and the contents emptied into the appropriate sample containers.

7.3.4 Sample Preservation

Immediately after collection, all samples requiring preservation must be preserved with the appropriate preservative. Consult Appendix A for the correct preservative for the particular analytes of interest. All samples preserved using a pH adjustment (except VOCs) must be checked, using pH strips, to ensure that they were adequately preserved. This is done by pouring a small volume of sample over the strip. Do not place the strip in the sample.

7.3.5 Special Sample Collection Procedures

Trace Organic Compounds and Metals

Special sample handling procedures should be instituted when trace contaminant samples are being collected. All sampling equipment, including pumps, bailers, water level measurement equipment, etc., which comes into contact with the water in the well must be cleaned in accordance with the cleaning procedures described in Appendix B. Pumps should not be used for sampling, unless the interior and exterior portions of the pump and the discharge hoses are thoroughly cleaned. Blank samples should be collected to determine the adequacy of cleaning prior to collection of any sample using a pump.

Filtering

As a standard practice, ground water samples will not be filtered for routine analysis. Filtering will usually only be performed to determine the fraction of major ions and trace metals passing the filter and used for flow system analysis and for the purpose of geochemical speciation modeling. Filtration is not allowed to correct for improperly designed or constructed monitoring wells, inappropriate sampling methods, or poor sampling technique.

When samples are collected for routine analyses and are filtered, such as under conditions of excessive turbidity, both filtered and non-filtered samples will be submitted for analyses. Samples for organic compounds analysis should not be filtered. Prior to filtration of the ground water sample for any reason other than geochemical speciation modeling, the following criteria must be demonstrated to justify the use of filtered samples for inorganic analysis:

1. The monitoring wells, whether temporary or permanent, have been constructed and developed in accordance with Section 6.
2. The ground water samples were collected using sampling techniques in accordance with this section, and the ground water samples were analyzed in accordance with US-EPA approved methods.

3. Efforts have been undertaken to minimize any persistent sample turbidity problems. These efforts may consist of the following:
 - Redevelopment or re-installation of permanent ground water monitoring wells.
 - Implementation of low flow/low stress purging and sampling techniques.
4. Turbidity measurements should be taken during purging and sampling to demonstrate stabilization or lack thereof. These measurements should be documented in the field notes.

If the ground water sample appears to have either a chemically-induced elevated turbidity, such as would occur with precipitate formation, or a naturally elevated colloid or fine, particulate-related turbidity, filtration will not be allowed.

If filtration is necessary for purposes of geochemical modeling or other **pre-approved** cases, the following procedures are suggested:

1. Accomplish in-line filtration through the use of disposable, high capacity filter cartridges (barrel-type) or membrane filters in an in-line filter apparatus. The high capacity, barrel-type filter is preferred due to the higher surface area associated with this configuration. If a membrane filter is utilized, a minimum diameter of 142 mm is suggested.
2. Use a 5 μm pore-size filter for the purpose of determining the colloidal constituent concentrations. A 0.1 μm pore-size filter should be used to remove most non-dissolved particles.
3. Rinse the cartridge or barrel-type filter with 500 milliliters of the solute (ground water to be sampled) prior to collection of sample. If a membrane filter is used, rinse with 100 milliliters of solute prior to sample collection.

Potential differences could result from variations in filtration procedures used to process water samples for the determination of trace element concentrations. A number of factors associated with filtration can substantially alter "dissolved" trace element concentrations; these include filter pore size, filter type, filter diameter, filtration method, volume of sample processed, suspended sediment concentration, suspended sediment grain-size distribution, concentration of colloids and colloidally-associated trace elements, and concentration of organic matter. Therefore, consistency is critical in the comparison of short-term and long-term results. Further guidance on filtration may be obtained from the following: 1) Metals in ground Water: Sampling Artifacts and Reproducibility (3); 2) Filtration of Ground Water Samples for Metals Analysis (4); and 3) Ground Water Sampling - A Workshop Summary (5).

Bacterial Sampling

Whenever wells (normally potable wells) are sampled for bacteriological parameters, care must be taken to ensure the sterility of all sampling equipment and all other equipment entering the well. Further information regarding bacteriological sampling is available in the following: 1) Sampling for Organic Chemicals and Microorganisms in the Subsurface (6); 2) Handbook for Evaluating Water Bacteriological Laboratories (7); and 3) Microbiological Methods for Monitoring the Environment, Water and Wastes (8).

7.3.6 Specific Sampling Equipment Quality Assurance Techniques

All equipment used to collect ground water samples shall be cleaned as outlined in Appendix B and repaired, if necessary, before being stored at the conclusion of field studies. Cleaning procedures utilized in the field (Appendix B), or field repairs shall be thoroughly documented in field records.

7.3.7 Auxiliary Data Collection

During ground water sample collection, it is important to record a variety of ground water related data. Included in the category of auxiliary data are water level measurements, well volume determinations, pumping rates during purging, and occasionally, drillers or boring logs. This information should be documented in the field records. Well volume determinations are described in Section 7.2.1.

Water Level Measurements

Water table measurements from the top of the well casings (referenced to National Geodetic Vertical Datum) in permanent wells, and ground surface elevations in temporary wells should be made to assist in determining the general direction of ground water flow and gradient. The methodology to be used to determine well water levels are given in Section 15.8. Tracer dyes and radioactive and thermal detection methods can be used to determine direction and velocities of flow (9). Also, a study of the general topography and drainage patterns will generally indicate direction of ground water flow.

The ground surface elevation and top of casing elevation at the wells should be determined by standard engineering survey practices as outlined in Section 15.

Well Pumping Rate - Bucket/Stop Watch Method

The pumping rate for a pump can be determined by collecting the discharge from the pump in a bucket of known volume and timing how long it takes to fill the bucket. The pumping rate should be in gallons per minute. This method shall be used primarily with pumps with a constant pump rate, such as gasoline-powered or electric submersible pumps. Care should be taken when using this method with some battery-powered pumps. As the batteries' charge decreases, the pump rate also decreases so that pumping rate calculations using initial, high pump rates may be erroneously high. If this method is used with battery-powered pumps, the rate should be re-checked frequently to ensure accuracy of the pumping rate calculations.

7.4 References

1. US EPA., RCRA Ground-Water Monitoring: Draft Technical Guidance, November 1992, Office of Solid Waste, EPA/530-R-93-001.
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3. Puls, Robert W., Don A. Clark, and Bert Bledsoe. Metals in Ground Water: Sampling Artifacts and Reproducibility. *Hazardous Waste and Hazardous Materials* 9(2): 149-162 (1992).
4. Puls, Robert W., and Michael J. Barcelona. filtration of Ground Water Samples for Metals Analysis. *Hazardous Waste and Hazardous Materials* 6(4): 385-393 (1989).
5. Ground Water Sampling - A Workshop Summary. Proceedings from the Dallas, Texas November 30 - December 2, 1993 Workshop. US EPA Office of Research and Development Robert S. Kerr Environmental Research Laboratory. EPA/600/R-94/205, January 1995.
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7. Handbook for Evaluating Water Bacteriological Laboratories, US EPA, ORD, Municipal Environmental Research Laboratory, Cincinnati, Ohio, 1975.
8. Microbiological Methods for Monitoring the Environment, Water and Wastes, US EPA, ORD, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, 1978.
9. "Groundwater", Section 18, USDA-SCS National Engineering Handbook, United States Department of Agriculture, Soil Conservation Service, 1978.